3-K
TREATMENT PLANT DISINFECTION ALTERNATIVES

FINAL ENVIRONMENTAL IMPACT STATEMENT

Brightwater Regional Wastewater Treatment System

APPENDICES

Brightwater
TREATMENT SYSTEM

Final

Appendix 3-K
Treatment Plant Disinfection Alternatives

August 2003

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King County has prepared a Draft Environmental Impact Statement (Draft EIS) and Final Environmental Impact Statement (Final EIS) on the Brightwater Regional Wastewater Treatment System. The Final EIS is intended to provide decision-makers, regulatory agencies, and the public with information regarding the probable significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County Executive Ron Sims has identified a preferred alternative, which is outlined in the Final EIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision, which will be made following the issuance of the Final EIS with accompanying technical appendices, comments on the Draft EIS and responses from King County, and additional supporting information. After issuance of the Final EIS, the King County Executive will select final locations for a treatment plant, marine outfall, and associated conveyances.

The County Executive authorized the preparation of a set of Technical Reports, in support of the Final EIS. These reports represent a substantial volume of additional investigation on the identified Brightwater alternatives, as appropriate, to identify probable significant adverse environmental impacts as required by the State Environmental Policy Act (SEPA). The collection of pertinent information and evaluation of impacts and mitigation measures on the Brightwater proposal is an ongoing process. The Final EIS incorporates this updated information and additional analysis of the probable significant adverse environmental impacts of the Brightwater alternatives, along with identification of reasonable mitigation measures. Additional evaluation will continue as part of meeting federal, state, and local permitting requirements.

Thus, the readers of this Technical Report should take into account the preliminary nature of the data contained herein, as well as the fact that new information relating to Brightwater may become available as the permit process gets underway. It is released at this time as part of King County's commitment to share information with the public as it is being developed.

INTRODUCTION

The purpose of this evaluation is to recommend a disinfection system alternative for predesign and/or identify additional data collection and analysis necessary to make the final recommendation. This technical memorandum supersedes the alternative analysis previously developed in the technical memorandum titled, *Draft Evaluation of Disinfection Processes for the Brightwater Siting Project*, May 15, 2002 (CH2M HILL), by incorporating refined design criteria, such as plant site location, process configuration, outfall size, length, and discharge location. Two possible disinfection options were evaluated on the basis of process advantages and disadvantages, sizing of components and order-of-magnitude cost estimates. These alternatives include:

- Delivered sodium hypochlorite
- Ultraviolet (UV) light (both low pressure, high intensity and medium pressure, high intensity)

The following disinfection alternatives were considered to be unsuitable for evaluation due to concerns about safety and environmental issues and/or reliability, effectiveness, and potentially higher cost:

- Chlorine gas
- Ozone
- Chlorine dioxide

One additional disinfection alternative was evaluated in the *Draft Evaluation of Disinfection Processes for the Brightwater Siting Project:*

- On-site generation of sodium hypochlorite

This alternative will be briefly described in this evaluation, but no order-of-magnitude costs are included.

STUDY AREA CHARACTERISTICS

Phase I of the Brightwater project will be designed for an average annual flow of 31 million gallons per day (mgd) with a peak hourly flow capacity of 130 mgd, assuming no flow attenuation upstream of the plant. This peak flow could be reduced to 100 mgd with attenuation. For the purposes of this evaluation, however, no flow attenuation will be assumed. The plant will be designed with split stream treatment. The primary plant processes will include activated sludge treatment with a membrane bioreactor (MBR) sized to handle a maximum flow of 38 mgd. Above 38 mgd, flow will be split from the grit chambers to a ballasted sedimentation process for high-rate clarification prior to disinfection. Phase II of the Brightwater project will expand primary and secondary treatment to a maximum non-attenuated capacity of 56 mgd before splitting occurs to ballasted sedimentation. The ballasted sedimentation units in Phase II will be sized for a peak capacity of 114 mgd (total non-attenuated plant capacity of 170 mgd). The flows and loads for the Brightwater project are summarized in Table 1.

TABLE 1
Brightwater Flows and Loads-Phase I and Phase II

Phase	Process	Start-up low flow, mgd	Avg annual flow, mgd[1]	Avg wet weather flow, mgd[1]	Peak month flow, mgd[1]	Peak day flow, mgd[1]	Peak hour flow, mgd (un-stored)[1]	Avg wet weather BOD, mg/L[1]	Avg wet weather TSS, mg/L[1]	Trans-mit-tance, percent[2]
I	Plant influent	4	31	36	51	99	130	200	207	N/A
	MBR, effluent	4	31	36	38	38	38	2.0	2.0	65
	Ballasted sedimenta-tion, effluent	0	0	0	13	61	92		40.6	42
	MBR + ballasted sedimenta-tion, effluent	0	31	36	51	99	130		25	50

TABLE 1
Brightwater Flows and Loads-Phase I and Phase II

Phase	Process	Start-up low flow, mgd	Avg annual flow, mgd[1]	Avg wet weather flow, mgd[1]	Peak month flow, mgd[1]	Peak day flow, mgd[1]	Peak hour flow, mgd (un-stored)[1]	Avg wet weather BOD, mg/L[1]	Avg wet weather TSS, mg/L[1]	Trans-mit-tance, percent[2]
II	Plant influent	N/A	47	54	76	148	170	185	180	N/A
	MBR, effluent	N/A	47	54	56	56	56	2.0	2.0	65[2]
	Ballasted sedimenta-tion, effluent	N/A	0	0	20	92	114		40.6	42
	MBR + ballasted sedimenta-tion, effluent	N/A	47	54	76	148	170		25	50

[1]Data from Brown and Caldwell Brightwater Predesign Preliminary Design Criteria/Sizing Information.
[2] Data from P. Jitnuyanont, *et al*., *UV Transmittance Study of King County Wastewater*, January 2003 (see Attachment A)
BOD = biochemical oxygen demand
TSS = total suspended solids

Two disinfection scenarios are evaluated for Phase I. The first is disinfecting the effluent directly downstream of the MBR and the ballasted sedimentation tank. This would require two separate disinfection units. The second scenario is disinfection of the split stream flows after they are recombined.

Several site locations were previously evaluated for the Brightwater plant. This disinfection evaluation assumes that the plant will be located at the proposed Route 9 site alternative. The proposed plant outfall will be located in the Puget Sound, approximately 9 miles from the plant site. Effluent quality assumed for the design is listed in Table 1.

King County has prepared the Draft Environmental Impact Statement on the Brightwater Regional Wastewater Treatment System (DEIS). The DEIS and Final EIS (FEIS) are intended to provide decision-makers, regulatory agencies and the public with information regarding the probably significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County executive Ron Sims has identified a preferred alternative, which is outlined in the DEIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision after additional analysis and public comments on the EIS are collected. Following issuance of the FEIS, the King County Executive will select final locations for a treatment plant, marine outfall, and associated conveyances.

In the interim, and in order to meet the requirement that the Brightwater project be operational in the year 2010, King County is proceeding with preliminary plans and designs and other work necessary to further refine the proposal and develop permit applications for the proposal. This ongoing work will not limit the choice of reasonable alternatives to be selected at the end of the EIS process.

PROCESS SELECTION

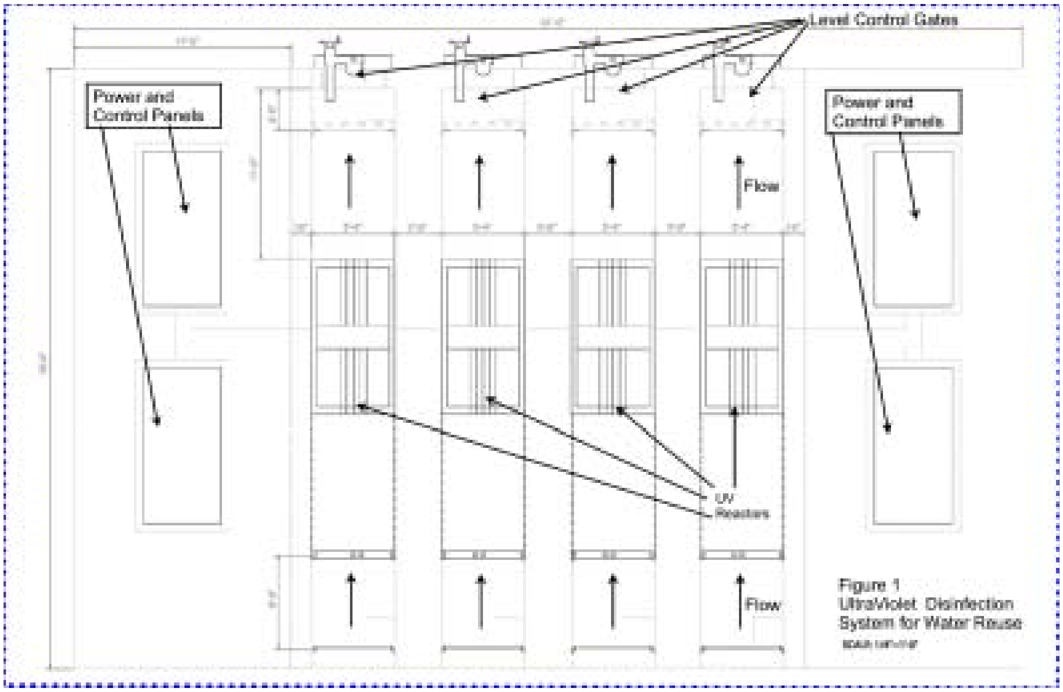
This technical evaluation is based on the assumption that the main plant flow will be treated by the MBR process. If conventional activated sludge is the selected option, the required hypochlorite and bisulfite doses will be higher. Also, the size of UV disinfection systems used for the process comparison would be somewhat larger due to the increased concentration of total suspended solids.

DISINFECTION/REUSE REGULATORY REVIEW

The State of Washington Department of Ecology (Ecology) regulates the design, construction and operation of wastewater treatment and reuse facilities in Washington. The Brightwater project includes disinfection of treated wastewater for discharge to Puget Sound. A portion of the MBR effluent would also receive additional disinfection and would be Class A Reclaimed Water. Reuse elements that are discussed in greater detail in a separate technical memorandum titled *Reclaimed Water Technology Review Evaluation of Potential Water Reuse Opportunities*. Regulations governing treatment for reuse or discharge are established as follows:

Reclamation and Reuse

Class A Reclaimed Water, in Washington, means reclaimed water that, at a minimum, is at all times an oxidized, coagulated, filtered, disinfected wastewater. The wastewater shall be considered adequately disinfected if the median number of total coliform organisms in the wastewater after disinfection does not exceed 2.2 per 100 milliliters (ml), as determined from the bacteriological results of the last 7 days for which analyses have been completed, and the number of total coliform organisms does not exceed 23 per 100 ml in any sample (Ecology, 1997). Washington State standards for reclamation of wastewater for reuse are based on conventional secondary effluent followed by coagulation and granular media filtration. The standards have not been updated to include emerging technologies, such as MBR treatment. The National Water Research Institute (NWRI) publication, "*Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*" is used to project future regulatory changes covering advanced technologies. NWRI requires coagulation and granular media filtration systems to produce an effluent with a turbidity of less than 2 NTU and requires a minimum UV dose of 100 mJ/cm^2. Membrane processes, such as MBR, are required to have a turbidity of less than 0.5 NTU, and the required disinfection dose is reduced to 80 mJ/cm^2. Coagulation is not required by NWRI for MBR effluent. A preliminary layout of a UV disinfection system for production of reclaimed water for off-site reuse is shown in Figure 1. This layout is provided to establish the required site area for the disinfection system and the equipment details may change substantially during design.



Discharge to Puget Sound

Discharge of treated water to Puget Sound, a navigable water of the United States, is regulated by Ecology under authority granted by the U.S. Environmental Protection Agency (EPA) and as delineated in a National Pollutant Discharge Elimination System (NPDES) permit to be issued for the facility. Because this permit has not been developed at this time, assumed bacterial standards are developed based on standards imposed on nearby POTW dischargers to Puget Sound.

The NPDES permit for Brightwater is anticipated to contain the bacterial limits listed in Table 2. In addition, because chlorine compounds used to disinfect wastewater are themselves toxic to many forms of marine life, the NPDES permit will limit chlorine residual in the plant effluent. The likely chlorine residual limit is also listed in Table 2. Contact times for chemical disinfection (based on a Puget Sound discharge and Ecology criteria) at average daily flow (daily average of the month with the highest flow) is 60 minutes and at peak daily flow is 20 minutes.

TABLE 2
Potential Brightwater Effluent Permit Requirements

Permit	Basis	Limit
Fecal coliform bacteria	Geometric monthly mean	200 counts per 100 ml.
	Maximum daily	400 counts per 100 ml.
Total residual chlorine	Monthly average	0.5[1] – 0.66 mg/L[2]
	Maximum daily	0.147[3] - 1.0 mg/L[1]

[1]Chlorine limits for Alderwood Water and Sanitation District plant at Picnic Point
[2]Chlorine limits for King County South Plant in Renton, Puget Sound discharge
[3]Chlorine limits for King County South Plant in Renton, Green River discharge

The total residual chlorine ranges listed in Table 2 are based on the NPDES permit for the nearby Alderwood Water and Sanitation District plant at Picnic Point and the NPDES permit for the King County South Plant in Renton. For purposes of this technical memorandum, the monthly average limit from Alderwood (0.5 mg/L) was assumed.

CHEMICAL DISINFECTION CRITERIA

Chlorination (Hypochlorite) Dosage

Based on historical chlorine usage data for King County's South Plant in Renton, the chlorine dosage for Brightwater was assumed to be 2.0 milligrams per liter (mg/L) for average secondary effluent flow. This dose rate will likely be sufficient for the MBR effluent. However, when high flows occur and treatment is achieved via ballasted sedimentation, the effluent quality will be reduced. Based on current literature, the chlorine dose will likely be on the order of 5.0 to 6.0 mg/L. To be conservative, a dose of 10 mg/L is used in this evaluation.

Dechlorination (Sodium Bisulfite) Dosage

Dechlorination is required to reduce the chlorine residual in the wastewater effluent before discharge to Puget Sound. Various chemicals can be used for dechlorination; however, sodium bisulfite solution is typically used when hypochlorite is used for disinfection. Determining the required dose of sodium bisulfite is typically more difficult than determining the required dose of hypochlorite due to variations in the chlorine residual at the outlet from the chlorine contact chamber or pipe. For example, at the South Treatment Plant in Renton, the outfall is 12 miles long. Chlorine residual is monitored at the 10-mile mark effluent transfer system (ETS) outfall vault) where the ETS enters Elliot Bay. The chlorine residual at the ETS outfall routinely drops below the maximum allowed permit limit of 0.66 mg/L by natural degradation. This has allowed South Plant to never use its chemical dechlorination for discharge to Puget Sound. For the Route 9 site location, dechlorination may be required but will likely be used infrequently considering the extended detention time and chlorine decay. The ratio required is 1.46 parts of sodium bisulfite ($NaHSO_3$) to remove 1 part of chlorine residual; the reaction is almost instantaneous, assuming good mixing of the bisulfite and chlorinated effluent.

Chemical Storage Volumes

The size and number of hypochlorite (NaOCl) storage tanks used in this evaluation is based on a 3-day shipping interval from the vendor plus provision of a 15-day emergency reserve, at average annual flow rate and dose. In theory, the concentration of available chlorine in NaOCl solution diminishes with time, and allowance must be made for this in computation of reserve requirements. The South Plant at Renton has not noticed the degradation of hypochlorite under normal use conditions. Off-gassing in unused lines and tanks has been observed and has been much more of a problem. For purposes of conservative design, a loss of 0.055 percent per day from 12.5 percent sodium hypochlorite solution was assumed. The available storage for bisulfite was assumed to be the same as that for hypochlorite, which is 18 days.

UV DISINFECTION CRITERIA

Typical secondary effluent properties were assumed to determine preliminary sizing of UV facilities for this evaluation. The following percent UV transmittance and effluent suspended solids concentrations from the various unit processes were assumed:

From MBR:

- UV Transmittance: 65 percent, average
- Total Suspended Solids Concentration: 2.0 mg/L[1]
- Max Particle Size: 30 microns[1]

From Ballasted Sedimentation:

- UV Transmittance: 42 percent, average
- Total Suspended Solids Concentration: 40.6 mg/L2
- Max Particle Size: 50 microns

From combined Ballasted Sedimentation and MBR:

- UV Transmittance: 50 percent, average
- Total Suspended Solids Concentration: 25.0 mg/L2
- Max Particle Size: 40 microns

REVIEW OF EXISTING DISINFECTION SYSTEMS

There is limited experience with running ballasted sedimentation followed by UV disinfection. In all cases, however, no special maintenance or operation practices were required, and adequate disinfection was achieved.

- Bremerton, WA-ballasted sedimentation followed by medium pressure UV disinfection. The nation’s first full-scale operation, the facility is designed to treat peak flows of 20 mgd, with discharge to the Port Washington Narrows section of the Puget Sound
- Sand Island, Hawaii-Disinfection of primary effluent with a medium pressure high intensity UV disinfection system
- Salem, OR-full-scale pilot, ballasted sedimentation followed by medium pressure UV disinfection
- Toledo, OH-full-scale pilot, ballasted sedimentation followed by medium pressure UV disinfection
- South Lyon, MI-designed with ballasted sedimentation and medium pressure UV disinfection (project is currently out to bid)

MBR technology is also relatively new, with limited full-scale systems in operation that are followed by UV disinfection. One facility currently nearing completion is the following:

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[1] This upper limit was assumed to account for filter plugging and/or tears in the membrane.

[2] These values were determined from a mass balance analysis conducted by Brown and Caldwell.

- Randolph Park, Pima County, AZ-MBR followed by UV disinfection

A substantial number of treatment plants use long outfalls for chlorine contact in place of contact basins at the plant site. One example is the Columbia Boulevard Wastewater Treatment Plant (CBWWTP) operated by the City of Portland. The CBWWTP disinfects with chlorine (soon to be using hypochlorite) at the plant site, and uses the 12,000-foot outfall pipe running to the Columbia River as contact time for disinfection. A dechlorination facility using sodium bisulfite was recently constructed at the river to remove chlorine immediately prior to discharge. Sampling for bacteria and chlorine residual is done at the new dechlorination station.

LOCATION OF CHEMICAL STORAGE AND FEED FACILITIES

Sodium hypochlorite

Sodium hypochlorite delivery, storage and feed facilities would be located at the proposed Route 9 treatment plant site alternative. The location onsite should be convenient to the ETS portal and to site roads designed for over-the-road chemical tank truck delivery. Roads should be designed for 40,000-pound tank truck loading and circulation, and a contained unloading area should be provided.

Sodium bisulfite

The proposed location of the sodium bisulfite feed facilities would be in the vicinity of proposed Portal 5. The facility should include contained unloading areas, storage tanks and feed pump facilities. Figure 2 presents a preliminary layout and the overall space requirements for the dechlorination facility. This site is selected for several reasons. The first reason is that it ensures compliance with the Ecology disinfection contact time criteria of 60 minutes of chlorine contact at the Average Design Flow, and 20 minutes at Peak Daily Flow, by allowing almost the entire ETS to act as a contact basin.

The second reason for selecting the proposed Portal 5 site to locate sodium bisulfite feed equipment is that the additional contact time would allow for a chlorine residual along the majority of the ETS, minimizing the chance for biological regrowth, as discussed below.

The third reason for locating the facilities at proposed Portal 5 is that the extended contact time would allow a maximum amount of natural degradation of the chlorine prior to dechlorination, resulting in decreased bisulfite requirements at proposed Portal 5.

In addition, locating the dechlorination facilities near the outfall allows for the outfall chlorine residual analyzer to serve as a control signal for the injection rate of bisulfite at the dechlorination facility, due to their relative proximity. Locating the dechlorination facility further from the outfall (such as proposed Portal 41) would require the installation of an additional chlorine residual analyzer at the dechlorination facility.

An alternative method of process control for dechlorination, which has been effectively used at other facilities, is oxidation-reduction potential (ORP). ORP measurement is an on-line control that can be more effective than chlorine residual control. An effluent sampling station would be constructed near the discharge to Puget Sound. A typical effluent sampling station would provide a chlorine residual analyzer, and any other samplers or instruments required to demonstrate permit compliance.

ONSITE DECHLORINATION FACILITIES FEASIBILITY

In most disinfection systems that use hypochlorite, a dechlorinating agent (such as sodium bisulfite) is added to eliminate the residual chlorine prior to discharge of the effluent into the receiving water. However, the chlorine residual decays over time, dependent on water temperature, pH, and the chemical composition of the effluent stream. Thus it is possible that chemically enhanced dechlorination may not be required with a sufficiently long outfall.

The South Plant at Renton has a 12-mile long, 96-inch outfall that discharges, on average, 73 mgd to the Puget Sound. Chemical dechlorination has not been necessary; chlorine doses are low enough and natural degradation within their outfall pipe is sufficient to easily meet the permitted limit. The South Plant uses an average applied chlorine dose of 1.3 mg/L to disinfect plant effluent within the chlorine contact chambers. Initial outfall pipe chlorine residuals of 0.69 mg/L and outfall residuals of 0.045 mg/L are typical. Because the Brightwater plant effluent, discharge point, and outfall would be similar to the South Plant's, and therefore the decay rate for chlorine, using historical data from the South Plant, was assumed to be:

$$\frac{C}{Co} = e^{-0.42t}$$

Where:

C= chlorine residual at time t, mg/L

Co= chlorine residual at time zero, mg/L

t= contact time, hours

Based on the decay rate of chlorine calculated above, the maximum initial chlorine residual was determined, assuming a final discharge concentration limit of 0.5 mg/L. This value represents the maximum concentration of chlorine allowed in the effluent, at the point of discharge. The maximum applied dosages of chlorine for the Brightwater plant are listed in Table 3. All values were based on a 9-mile outfall consisting of two 60-inch pipes running full at all flow rates. In addition, the required chlorine contact times are shown and the required contact zone length of the ETS is calculated.

TABLE 3
Applied Chlorine Dose Limits and ETS Disinfection Contact Lengths for the Brightwater Plant

Phase of project	Flow, mgd	Contact time, hours	Max applied dose, mg/L	Effluent velocity, fpm	Required contact time, min	Required contact pipe length, feet[1]
I	4	83.8	**>>50**	9.5	N/A	**N/A**
	31	10.8	**46.7**	73.3	N/A	**N/A**
	36	9.31	**25.0**	85.1	N/A	**N/A**
	51	6.57	**7.9**	121	60	**7,260**
	99	3.38	**2.1**	234	20	**4,680**
	100	3.35	**2.0**	236	N/A	**N/A**
	130	2.58	**1.5**	307	N/A	**N/A**

TABLE 3
Applied Chlorine Dose Limits and ETS Disinfection Contact Lengths for the Brightwater Plant

Phase of project	Flow, mgd	Contact time, hours	Max applied dose, mg/L	Effluent velocity, fpm	Required contact time, min	Required contact pipe length, feet[1]
II	47	7.13	**10.0**	111	N/A	**N/A**
	54	6.20	**6.8**	128	N/A	**N/A**
	76	4.41	**3.2**	180	60	**10,800**
	140	2.39	**1.4**	331	N/A	**N/A**
	148	2.26	**1.3**	350	20	**7,000**
	170	1.97	**1.1**	402	N/A	**N/A**

[1] Distance to Portal 41 is 12,000 feet

The above analysis assumes that all plant effluent (MBR and ballasted sedimentation) would be disinfected with sodium hypochlorite. Based on the results of the South Plant at Renton, 2 mg/L is a reasonably good estimate of typical applied chlorine dosages. From Table 3, however, it can be seen that when flows exceed approximately 102 mgd, the maximum applied dose drops below 2 mg/L and dechlorination of the effluent becomes necessary. Chlorine residual should be monitored in the ETS to ensure adequate dechlorination. At a minimum, monitoring should be done at a portal as close to the shoreline as possible. Current Washington State regulations do not specifically address the requirements for disinfection of MBR effluent. The fine membrane pores will remove coliform bacteria while allowing a portion of the pathogens to pass through to the effluent. For example, all viruses will pass through the membranes, while fecal coliform results will indicate little need to disinfect. Discussions with regulators are required to determine appropriate disinfection criteria. One possibility is that minimum hypochlorite dose rates and contact times may be required, or minimum UV doses may be required if UV is the selected process. Performance testing may require the use of a different indicator organism, such as the MS2 coliphage.

The dechlorination chemical must be added downstream of the chlorine contact zone of the ETS. Based on the chlorine contact time stated above, the required length of the contact chamber is approximately 10,800 feet. The dechlorination facility could be installed as close to the Route 9 plant site as Portal 41, which is located approximately 12,000 feet from the plant. However, for the purposes of this evaluation, the dechlorination facilities would be located at Portal 5.

REGROWTH AND SLIME CONTROL IN THE ETS

It is possible that some amount of biological growth could occur in the ETS tunnel, due to the length of the ETS and the natural degradation of chlorine residual within the ETS. Regrowth would be more likely at lower flows, when travel times within the ETS are the greatest. Biological growth may occur along the sidewalls of the tunnel where submergence would vary due to changes in effluent flow rates. One scenario for dealing with the potential for biological growth is to do nothing. Effluent from the plant would be high quality (BOD < 5 mg/l) during most of the year when flow splitting is not occurring; therefore there would be little organic matter in the effluent to encourage biological growth. There are no regulatory drivers that require that biological growth be controlled in effluent pipelines. Examples of this same practice exist at King County's South Plant and the Central Kitsap County Wastewater Treatment Plant. Effluent from both plants is disinfected and confirming fecal coliform samples are drawn from a point immediately downstream from the point in the process where disinfection is complete. However, both plants have long effluent conveyance lines downstream from their disinfection completion points to their actual physical outfalls in Puget Sound. Neither of these plants is currently required by Ecology to address any concerns of biological growth in the conduits downstream of the disinfection completion points.

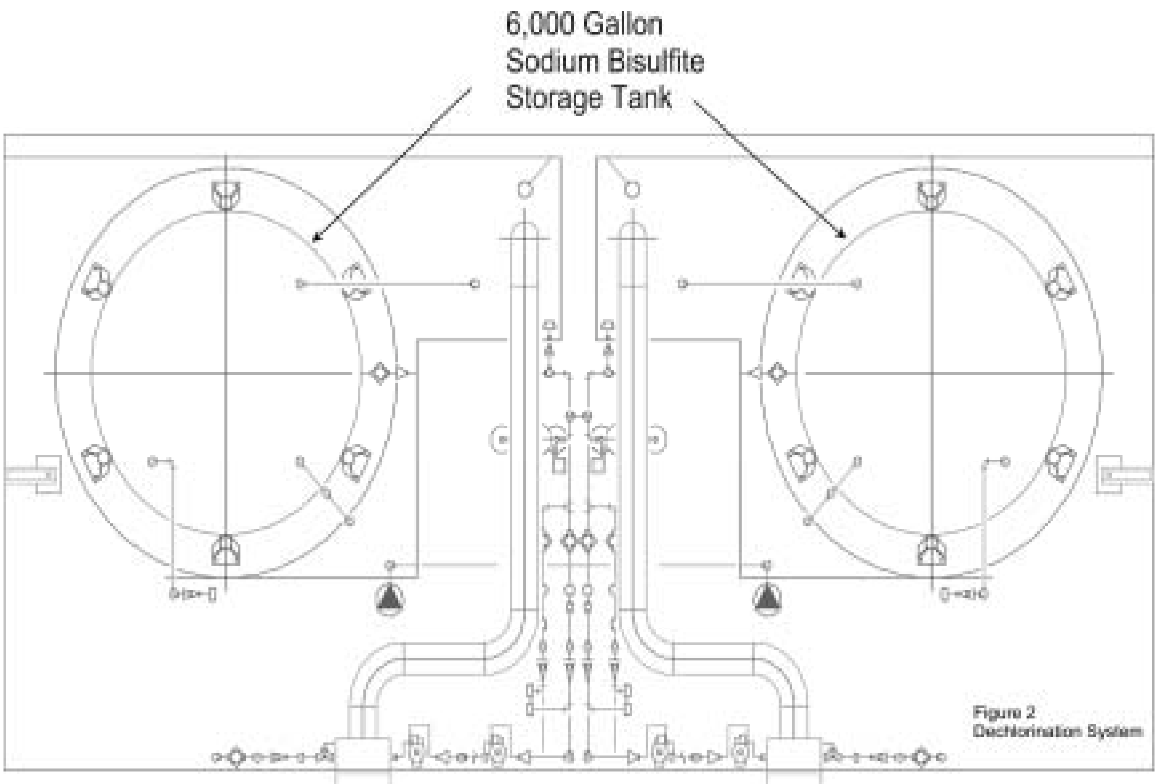

Figure 2
Dechlorination System

If, however, it becomes desirable to periodically control regrowth in the ETS tunnel, methodologies adapted from municipal water main practices can be utilized. Regrowth in municipal water mains does occur whenever pipe mains are exposed over time to zero or very low dosages of residual chlorine. Control of regrowth is necessary to avoid foul taste and odor problems in water distribution mains. The City of Everett, for example, periodically increases its chlorine residual in select water mains and flushes that water to nearby receiving streams to control regrowth. The flushed water is manually dechlorinated prior to discharge to the environment. This same practice could be adapted for the ETS tunnel. The chlorine residual in the tunnel could periodically be increased, followed by manually dosing of powdered or liquid dechlorination agents at Portal 5.

DISINFECTION SYSTEM ALTERNATIVE DEVELOPMENT

The disinfection options for Brightwater are identified and described below. For each of the options, an overview of the main features and operational characteristics is given. Preliminary design data is then given for each system, based on the flows and loads presented in Table 1. Following the design data, an initial screening process is performed to eliminate unsuitable options and identify the most promising options for Brightwater.

Sodium Hypochlorite Generated On-site

With an onsite sodium hypochlorite generation system, an electric current is applied to a concentrated brine solution or seawater to create sodium hypochlorite. The system feeds the pretreated brine to hypochlorite generators. The cells electrolyze the brine into a sodium hypochlorite solution as shown in the following equation:

NaCl + H2O + 2e = NaOCl + H2
(Salt + Water + 2e = Sodium Hypochlorite + Hydrogen)

Hydrogen is contained and vented to atmosphere. The hypochlorite solution is delivered to a tank for storage. A metering pump delivers the solution to its injection point in the treatment system.

Using seawater as the source of the brine is possible. However, pretreatment of the seawater would be required to remove the calcium carbonate and iron which precipitates in the alkaline side of the electrolysis cell, and the wastes from the pretreatment would be discharged in the outfall back to Puget Sound. In addition, the seawater would need to be concentrated before being electrolyzed. Due to the complexity of using seawater as the source of brine, and the additional costs for the seawater pretreatment equipment, only purchasing high purity salt as the brine source was considered feasible in this evaluation.

High purity, food-grade salt is delivered via trucks. The salt is dissolved into a brine and fed to hypochlorite generators. Approximately 3.5 pounds of salt are required to produce 1 pound of available chlorine in hypochlorite solution. The entire brine solution, with the generated hypochlorite, is used as the disinfectant. The hypochlorite solution strength is about 0.8 percent chlorine by weight, and 15 gallons of the dilute solution contain 1 pound of available chlorine. Because the solution is much more dilute than concentrated hypochlorite that is produced commercially, hypochlorite generated onsite does not degrade nearly as rapidly, and is much less corrosive than the concentrated hypochlorite. In addition, on-site generation reduces the risk and cost of transporting disinfectant to the site.

An onsite hypochlorite generation system would consist of a water softener, salt storage/brine tanks; brine feed pumps, hypochlorite generators, hypochlorite day tanks, hypochlorite metering pumps, and an acid cleaning system for the generators’ electrolytic cells. The electrolytic cells must be cleaned regularly with an acid solution, which produces a concentrated waste acid byproduct. Typically, the cells require cleaning every 2,000 to 4,000 hours of service. The cleaning frequency depends on the salt purity and water quality. In addition, the electrolytic cells require replacement about every 3 to 5 years, depending on the hours of operation.

Preliminary capital cost estimates developed for the *Draft Evaluation of Disinfection Processes for the Brightwater Siting Project* indicated that the onsite hypochlorite generation system would be 40 to 50 percent more expensive than the delivered hypochlorite system with no added benefits. For this reason, the onsite hypochlorite generation alternative was not considered further in this evaluation.

Delivered Sodium Hypochlorite Solution

As a chlorine-based product, hypochlorite functions the same as dissolved chlorine gas for disinfection, but has seen greater use recently because of public and employee safety concerns associated with the use of compressed gaseous chlorine. In communities such as San Francisco, California, where transport of chlorine within the city limits is prohibited by ordinance, sodium hypochlorite is used exclusively for water and wastewater disinfection. Hypochlorite is more expensive than chlorine when compared on the basis of price per pound of available chlorine. In addition, hypochlorite solution is more corrosive than a chlorine solution formed using gaseous chlorine due to its typically higher concentration. Hypochlorite solution is subject to degradation, and the amount of available chlorine in the solution decreases over time. Degradation depends on time, temperature, and initial concentration. Mixing of hypochlorite solution with other chemicals may create hazardous conditions because certain mixtures can cause chlorine gas to be generated and released. These chemicals include acids or strong reducing agents such s sodium bisulfite.

Industrial grade hypochlorite solution is available in strengths up to 16 percent with 12.5 percent being the most common. Household bleach, by comparison, is a 5 to 6 percent sodium hypochlorite solution. Delivery is made in tank trucks or railcars. Approximately 1 gallon of 12.5 percent solution strength provides the equivalent of 1 pound of chlorine. Sodium hypochlorite is handled much like other common wastewater treatment chemicals. As a liquid, the chemical is stored in tanks and is pumped to the application point. Dosing is generally controlled with chemical metering pumps. Sodium hypochlorite is harmful if swallowed or inhaled. Sodium hypochlorite solution is much more corrosive than a chlorine solution formed using gaseous chlorine. It causes irritation to eyes, skin and respiratory tract, and causes substantial but temporary eye injury. Occupational Safety and Health Administration (OSHA) has established the permissible limit for employee exposure to 0.5 ppm as a time-weighted average over 8 hours. Goggles, gloves, and long sleeves are required when handling hypochlorite solution.

Delivered Sodium Bisulfite Solution

Sodium bisulfite solution is typically used for dechlorination when using hypochlorite for disinfection. Sodium bisulfite’s storage, handling, use, and equipment requirements are similar to that of hypochlorite. Solution strengths of 38 percent are standard and the solution is generally delivered by tank truck or in drums or totes, although a commercial 25 percent solution is also available. The 38 percent solution has the specific gravity of 1.3 and contains 3.5 lbs of sulfite per gallon. Sodium bisulfite is an irritant to the skin, eyes, nose, and respiratory tract. OSHA has established the permissible limit for employee exposure to sodium bisulfite of 1.6 ppm in air as a time-weighted average over 8 hours.

UV Disinfection

Ultraviolet (UV) light is accepted as an effective wastewater disinfectant to control bacteria and viruses. UV disinfection is a physical disinfection method while other disinfection methods rely on chemical agents. Irradiation with UV light at a wavelength of 254 nanometers (nm) penetrates the cell wall and causes photochemical damage to the cell’s nucleic acids (DNA and RNA). The wavelength of 254 nm is used because the cell’s nucleic acids are the most important absorbers of energy of light at this wavelength. Because the DNA and RNA carry genetic information for reproduction, damage to these substances effectively prevents replication of the cell. Because UV light is not a chemical agent, no unwanted disinfection byproducts, such as chlorinated organic compounds, are produced. While certain chemical compounds may be altered by UV exposure, the energy levels used in wastewater are generally too low to significantly alter existing water quality constituents.

Advantages supporting UV disinfection include short contact time, on the order of seconds, simplicity of operation, and negligible chemicals used in the process.

The sources of the UV light for disinfection systems are mercury vapor lamps, which are operated at either 10^{-3} to 10^{-2} torr (low pressure lamps) or 10^{2} to 10^{3} torr (medium pressure lamps). A torr is a unit of pressure common to the UV industry. One torr is equivalent to approximately 0.02 pound per square inch. These two ranges of operating pressure give the highest conversion of electrical energy to light output. Low pressure lamps are more efficient in producing germicidal UV, but the total UV output is weaker than a medium pressure lamp. The low pressure, high intensity lamps have special design features to maintain mercury pressure at an optimum level under high discharge currents. The characteristics of these lamp systems are summarized in Table 4, and described in further detail below.

TABLE 4
UV Lamp Type Comparison

Lamp Type	Installation	Advantages	Disadvantages
Low Pressure, Low Intensity	Racks of lamps installed in open channels, with nominal 3-inch spacing between lamps.	Proven technology. Energy efficient. Long lamp life.	Cleaning can be labor intensive. Not recommended by manufacturers for application greater than 20 mgd.
Low Pressure, High Intensity	Racks of lamps installed in open channels, with a nominal 3-inch spacing between lamps.	Due to high intensity output, requires less space than conventional low intensity lamps. More energy efficient than medium pressure lamps. Longer lamp life than medium pressure lamps.	Relatively new technology. Lamps can be proprietary.
Medium Pressure	Lamps typically installed in a pipe or custom flow through reactor, specific to a particular manufacturer.	Proven system, with numerous installations since the mid-1990s. Number of lamps required is significantly reduced from low pressure, low intensity systems, resulting in significantly lower capital costs. Automated cleaning systems reduce maintenance.	Less energy efficient than low pressure UV lamps (more energy wasted on heat and production of UV radiation outside the optimal range). After a power outage, the system must be allowed to cool down for approximately 15 minutes prior to restarting.

Mercury contamination of the wastewater effluent is possible, but not common. The mercury in the lamp is a single drop and almost all the mercury remains in liquid form during the operation of the lamp. With proper screening and filtration, there is minimal risk of breaking lamps in the disinfection channels. There is the potential for lamp breakage when lamp banks are removed from channels for cleaning or replacement. However, several of the newer UV disinfection systems have automatic, in-channel wiper systems that minimize lamp removal.

Low Pressure High Intensity UV Lamp Systems

The low pressure high intensity UV systems are relatively new for large wastewater disinfection applications in North America, but have been utilized in Europe for many years. This technology achieves a high intensity UV output while retaining the relatively low energy consumption associated with low pressure lamps. Low pressure high intensity systems use five to seven times the number of lamps as medium pressure systems, but require less than half the energy to provide equivalent disinfection performance. For the low pressure high intensity UV systems, the open-channel horizontal and parallel-to-flow systems are most applicable for wastewater disinfection and are considered in this evaluation.

The horizontal and parallel-to-flow system has an arrangement that is similar to the low pressure conventional systems. The manufacturers claim longer life, stable output versus water temperature, and 3-times higher UV Type C output than those for the low pressure conventional systems. The manufacturers also claim higher operating efficiency than medium pressure lamp systems. Most low pressure, high intensity horizontal and parallel-to-flow systems have in-place automatic wiping systems to periodically clean quartz sleeves during operation. There are several recent installations of these UV systems in North America and numerous installations around the world including a 220-mgd facility in Manukau, New Zealand. The design life of low pressure, high intensity lamps is generally expected to by 8,000 hours, depending on the operating lamp output.

Medium Pressure, High Intensity UV Lamp Systems

Medium pressure mercury lamp high intensity UV systems have been used since the late 1980s for wastewater disinfection in North America. There are three types of designs using this type of lamp:

- Closed channel horizontal and parallel-to-flow
- Closed channel horizontal and perpendicular-to-flow
- In-line horizontal and perpendicular-to-flow

The medium pressure lamps generate significantly more UV light per inch of arc length than low pressure lamps. The total emission in UV-C from a medium pressure lamp is roughly 50 to 80 times higher than the intensity from a low pressure lamp. However, these medium pressure lamps produce a broad spectral energy distribution over the germicidal wavelengths that have different levels of germicidal effectiveness. When compared with the UV intensity of a low pressure lamp, the radiation at each wavelength has to be corrected based on the relative germicidal effectiveness. The common arc length of medium pressure lamps for disinfection purposes is about one-quarter of the length of a 64-inch low pressure lamp. Combining the effect of the broad emission spectrum and shorter lengths, the UV intensity from a medium pressure lamp is typically about 10 to 20 times higher than a low pressure mercury lamp.

The first medium pressure UV system in North America was installed in Lewisburg, Ohio, in 1987. Since 1987, many medium pressure high intensity UV systems have been constructed.

The lamp arrangement of a medium pressure lamp system is similar to a low pressure lamp system (i.e., horizontal and parallel-to-flow). The lamps are assembled in modules that are grouped to form lamp banks. One difference is that the lamps are located inside an enclosed reactor instead of an open channel. Each reactor contains two banks of lamps arranged end-to-end and in series. The replacement of lamps in a high intensity system typically requires taking the lamp module out of the water. The UV equipment provides a device for lifting the lamp module.

The life of medium pressure lamps depends on the operating power levels. The higher the operating power levels, the more waste heat must be dissipated and the shorter the lamp life. The design life of a medium pressure lamp is generally expected to be shorter than a low pressure lamp; it ranges from 3,000 to 8,000 hours, depending on the operating lamp output.

DEVELOPMENT OF OPTIONS

In the following section, the alternatives for the Brightwater treatment plant are developed based on Phase II flows and loads, as presented in Table 1. Equipment sizing is given, and doses of chemicals/UV are given, where appropriate.

Option 1 - Sodium Hypochlorite Delivered for In-plant Uses

This option considers disinfection of up to 38 mgd of MBR effluent and 92 mgd of ballasted sedimentation effluent (130 mgd total) using sodium hypochlorite delivered by tank trucks to the site. The dechlorination chemical (sodium bisulfite) is also delivered in tank trucks and stored on-site. The volume of disinfection basins and chemical storage tanks are determined below. The capital cost estimate includes storage tanks, metering pumps, PVC piping and contact basin construction, and equipment installation. A schematic of this alternative is shown in Figure 3.

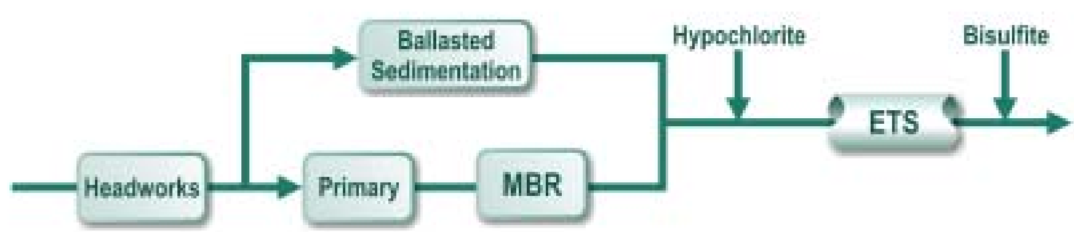

Figure 3. Option 1- Sodium Hypochlorite Disinfection

Disinfection Basins

The required contact period, as per State of Washington guidelines, is a minimum of 1 hour at average design flow or 20 minutes at peak daily flow, whichever is greater. Contact basins should be designed such that detention times are less than 2 hours for initial flows. For purposes of this evaluation, the first 12,000 feet of the Effluent Transfer System (ETS) is assumed to function as a contact basin, and provides approximately 2.7 hours at annual average flows during Phase I and

30 minutes of contact time at peak hour flows during Phase II. Therefore, no on-site contact basin is required with this alternative.

Sodium Hypochlorite Storage

Sodium hypochlorite storage facilities are sized for 18 days of disinfection at annual average flows and doses. The flow through the ballasted sedimentation process assumes that the 1-year recurrence wet weather flow of 50 mg through ballasted sedimentation occurs over a 7-day period. Flows from the MBR are assumed to be dosed with 2.0 mg/L of hypochlorite, and flows from the ballasted sedimentation are assumed to be dosed with 10.0 mg/L of hypochlorite. Storage capacity also assumes a 0.055% per day loss from the 12.5% solution. Approximately 1 gallon of 12.5% solution strength provides the equivalent of 1 pound of chlorine. Because sodium hypochlorite solution is corrosive, double-walled PVC piping is generally required to deliver sodium hypochlorite to the contact basin.

Total required hypochlorite storage in Table 5 is based on the one-year recurrence wet weather flow of 50 mg through ballasted sedimentation occurring over a 7-day period. The required storage increases by 15,100 gallons when the 5-year recurrent wet weather flow of 231 mg is used. Total storage goes to 29,200 gallons for the 10-year recurrent wet weather flow of 400 mg. The cost estimates for Phase I assume three 5,000-gallon storage tanks are provided. Installation of one additional tank could be postponed until Phase II.

TABLE 5
Option 1: Sodium Hypochlorite Storage for Disinfection of Combined Effluent at the Brightwater Plant

Parameter	Value
Average annual flow Phase I, mgd	31
Average annual flow Phase II, mgd	47
Total annual flow volume through ballasted sedimentation, million gallons	50
Chlorine dose for MBR effluent, mg/L	2.0
Chlorine dose for ballasted sedimentation effluent, mg/L	10.0
Chlorine required (at Phase I average annual flow), lb/day	517
Chlorine required (at Phase II average annual flow), lb/day	784
Sodium hypochlorite required (at Phase I annual average flow), gallons/day	517
Sodium hypochlorite required (at Phase II annual average flow), gallons/day	784
Required storage volume for 18 days at Phase I annual average flow (corrected for decay of chlorine), gallons	10,200
Required storage volume for 18 days at Phase II annual average flow (corrected for decay of chlorine), gallons	15,500
Total Phase I annual volume, gallons	211,400
Total Phase II annual volume, gallons	318,900

Sodium Bisulfite Storage Volume

The dose of sodium bisulfite is not dependent on quality of effluent, but rather the chlorine residual concentration and volume of flow. Therefore, 18 days of storage would be provided during peak week flow conditions. Assuming the strength of delivered sodium bisulfite solution is 3.5 lb/gal and a 38 percent solution, the storage volume is calculated in Table 6. For purposes of this evaluation, it was assumed that sufficient sodium bisulfite would be added to the effluent downstream of the contact basin to reduce the chlorine residual to 0.0 mg/L. Based on historical data from the South Plant in Renton, it was also assumed that the chlorine residual at the end of the contact basin would be approximately 0.8 mg/L. In practice, a residual chlorine analyzer could be installed at the end of the contact basin, and bisulfite would be added only when the concentration of chlorine exceeds a specified value. Due to the relatively small storage volume required, and the stability of sodium bisulfite, a storage volume of 5,000 gallons was selected to minimize chemical cost. Sodium bisulfite is also commercially available as a 25 percent solution, which would require larger storage tanks and feed systems, as compared to the 38 percent solution.

TABLE 6
Option 1: Sodium Bisulfite Storage for Dechlorination of Combined Effluent at the Brightwater Plant

Parameter	Value
Phase I average annual flow, mgd	31
Phase II average annual flow, mgd	47
Total annual flow volume through ballasted sedimentation, million gallons	50
Sodium bisulfite dosage, mg/L	1.0
Delivered sodium bisulfite solution strength, lb/gal	3.5
Phase I sodium bisulfite use at annual average flow, lb/day	259
Phase II sodium bisulfite use at annual average flow, lb/day	584
Phase I required storage volume (18 days at annual average flow), gallons	1,300
Phase II required storage volume (18 days at annual average flow), gallons	2,000
Phase I total annual volume, gallons	26,800
Phase II total annual volume, gallons	41,000

The sodium bisulfite storage tank volume should be at least 5,000 gallons to accept a complete tank truck delivery.

Option 2 - Ultraviolet (UV) Light - Separate Disinfection of MBR and Ballasted Sedimentation Flow Streams

This option uses UV disinfection on the split stream flows, prior to discharging the flows to the ETS. A secondary source of power would be provided; therefore, no additional chemical disinfection treatment for backup is considered.

The UV disinfection reactor basins were designed to provide:

- Adequate submergence of the UV lamps.
- Plug flow characteristics.
- Minimum head loss.

A sketch of the UV system is shown in Figure 4. Both low pressure, high intensity and medium pressure, high intensity alternatives are developed for this option. The systems are sized for the Phase II flows, but power consumption is stated for the Phase I flows.

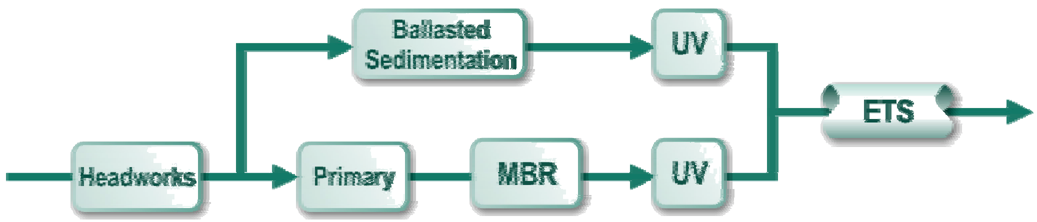

Figure 4. Option 2- Separate UV Disinfection

Low Pressure High Intensity UV System

The low pressure, high intensity system is sized to treat the flows from the MBR and the ballasted sedimentation process. The sizing of the units is listed in Table 7. The ballasted sedimentation process was sized for a peak flow rate of 114 mgd, but based on a flow recurrence evaluation; the average annual flow volume treated by this process would be approximately 50 mgd.

TABLE 7
Option 2: Low Pressure High Intensity UV System for the Disinfection of Separate Effluent Streams at the Brightwater Plant

Parameter	Value MBR system	Value ballasted sedimentation
Phase I average annual flow rate, mgd	31	-
Phase II average annual flow rate, mgd	47	-
Total annual flow, million gallons	17,155	50
Maximum flow rate, mgd	56	114
Transmittance, %	65	42
No. of channels	2	2
No. of banks per channel	3	4
No. of modules per bank	5	12
No. of lamps/module	18	18
Total no. of lamps required	540	1,728
Channel length, feet	35.8	34.5

TABLE 7
Option 2: Low Pressure High Intensity UV System for the Disinfection of Separate Effluent Streams at the Brightwater Plant

Parameter	Value MBR system	Value ballasted sedimentation
Channel width, inches	60	113
Channel depth, inches	61	58
Peak Power Draw, kW	162	584
Phase I estimated average power, kW	80	42
Hrs per year at avg. power	8,760	250[1]
Phase I annual total kWh consumed	700,800	10,500[1]
Phase I average power consumed, kWh/day	1,920	29

[1] Dependent on rainfall conditions.

Medium Pressure High Intensity UV System

The medium pressure, high intensity system is sized to treat the flows from the MBR and the ballasted sedimentation process. The sizing of the units is listed in Table 8. The ballasted sedimentation process was sized for a Phase II peak hour flow rate of 114 mgd, but based on a flow recurrence evaluation; the average annual flow volume treated by this process would be approximately 50 mgd.

TABLE 8.
Option 2: Medium Pressure High Intensity UV System for the Disinfection of Separate Effluent Streams at the Brightwater Plant

Parameter	Value MBR system	Value ballasted sedimentation
Phase I average annual flow rate, mgd	31	-
Phase II average annual flow rate, mgd	47	-
Maximum flow rate, mgd	56	114
Transmittance, %	65	42
No. of channels	1	2
No. of banks per channel	3	4
No. of modules per bank	3	4
No. of lamps/module	20	24
Total no. of lamps required	180	768
Channel length, feet	37.9	38.7
Channel width, inches	64	69
Channel depth, inches	155	160

TABLE 8.
Option 2: Medium Pressure High Intensity UV System for the Disinfection of Separate Effluent Streams at the Brightwater Plant

Parameter	Value MBR system	Value ballasted sedimentation
Total Power Draw, kW	336	2,420
Phase I estimated average power, kW	191	275
Hrs per year at avg. power	8,760	250[1]
Phase I annual total kWh consumed	1,673,160	68,750[1]
Phase I average power consumed, kWh/day	4,584	188

[1] Dependent on rainfall conditions.

Option 3 - Ultraviolet (UV) Light - Combined Disinfection of MBR and Ballasted Sedimentation Flow Streams

This alternative is designed to recombine the split stream flows prior to disinfection with a UV system. A sketch of the system is shown in Figure 5. Both low pressure, high intensity and medium pressure, high intensity alternatives are developed for this option.

Low Pressure High Intensity UV System

The low pressure, high intensity system is sized to treat the combined flows from the MBR and the ballasted sedimentation process. The sizing of the unit is listed in Table 9. The systems are sized for the Phase II flows, but power consumption is stated for the Phase I flows.

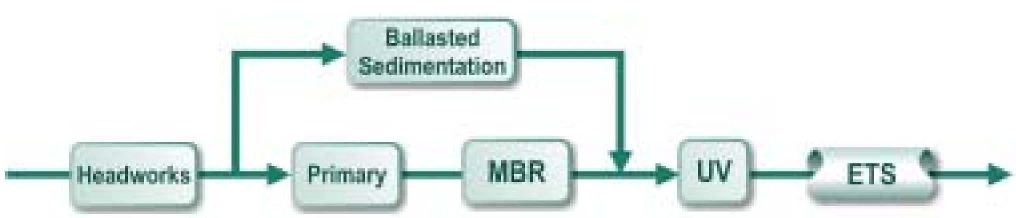

Figure 5. Option 3- Combined UV Disinfection

TABLE 9
Option 3: Low Pressure High Intensity UV System for the Disinfection of Combined Effluent at the Brightwater Plant

Parameter	Value
Phase I average annual flow rate, mgd	31
Phase II average annual flow rate, mgd	47

TABLE 9
Option 3: Low Pressure High Intensity UV System for the Disinfection of Combined Effluent at the Brightwater Plant

Parameter	Value
Maximum flow rate, mgd	170
Transmittance, %	50
No. of channels	3
No. of banks per channel	4
No. of modules per bank	12
No. of lamps/module	24
Total no. of lamps required	3,456
Channel length, feet	34.5
Channel width, inches	162
Channel depth, inches	58
Total Power Draw, kW	1,034
Phase I estimated average power, kW	109
Hrs per year at avg. power	8,760
Phase I annual total kWh consumed	954,840
Phase I average power consumed, kWh/day	2,616

Medium Pressure High Intensity UV System

The medium pressure, high intensity system is sized to treat the flows from the MBR and the ballasted sedimentation process. The sizing of the units is listed in Table 10.

TABLE 10
Option 3: Medium Pressure High Intensity UV System for the Disinfection of Combined Effluent at the Brightwater Plant

Parameter	Value
Phase I average annual flow rate, mgd	31
Phase II average annual flow rate, mgd	47
Maximum flow rate, mgd	170
Transmittance, %	50
No. of channels	2
No. of banks per channel	4
No. of modules per bank	5

TABLE 10
Option 3: Medium Pressure High Intensity UV System for the Disinfection of Combined Effluent at the Brightwater Plant

Parameter	Value
No. of lamps/module	24
Total no. of lamps required	960
Channel length, feet	38.7
Channel width, inches	78
Channel depth, inches	160
Peak Power Draw, kW	2,688
Phase I estimated average power, kW	275
Hours per year at avg. power	8,760
Phase I annual total kWh consumed	2,409,000
Phase I average power consumed, kWh/day	6,600

Option 4-UV and Hypochlorite Disinfection Combination

This alternative assumes that hypochlorite is added to the effluent stream of the ballasted sedimentation and that UV disinfection is used on the MBR effluent. Bisulfite would not be necessary within the ETS during normal operation because of the dilution of the residual when the split streams are recombined due to the dilution factor and the decay of chlorine in the ETS. At peak flows, however, it is possible that dechlorination would be required to meet permit limits. In this option, the UV system is sized for a Phase II peak flow of 56 mgd, and the hypochlorite system is sized for a Phase II peak flow of 114 mgd. Costs are provided for Phase I flow values of 31 and 92 mgd, respectively. A sketch of the system is shown in Figure 6.

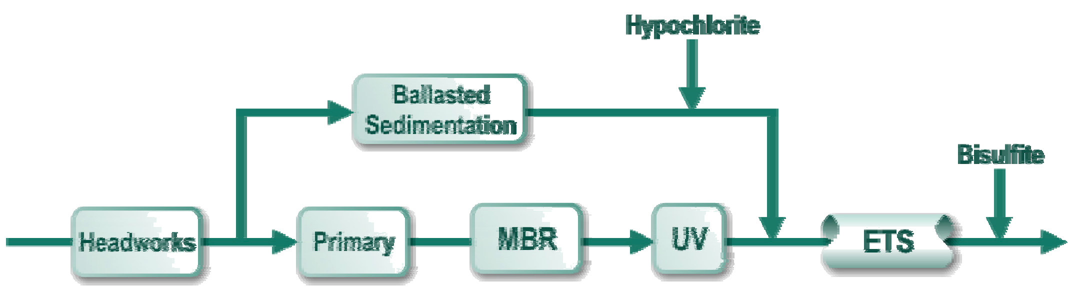

Figure 6. UV Disinfection and Hypochlorite Combination

For the purposes of this evaluation, it was assumed that the ballasted sedimentation effluent would mix with 38 mgd of MBR effluent only during the four wettest months of the winter. Total flow through the ballasted sedimentation was assumed to be 50 million gallons per year. Storage was provided to chlorinate this total volume of flow. Average chlorine residual from the ballasted sedimentation unit was assumed to be 10 mg/L. Based on this assumption, combined chlorine residuals could exceed the maximum applied dosage limits shown in Table 3 at higher plant flows. Therefore, dechlorination is also necessary under this alternative. These volumes are summarized in Tables 11 and 12. Although both UV options are presented below, for purposes of this evaluation, only the medium pressure high intensity system is evaluated in the cost analysis.

TABLE 11
Option 4: Sodium Hypochlorite and Sodium Bisulfite Storage for the Disinfection of Ballasted Sedimentation Effluent at the Brightwater Plant

Parameter	Value
Total annual flow through ballasted sedimentation unit, million gallons	50
Chlorine dose for ballasted sedimentation effluent, mg/L	10
Chlorine required, lb/year	4,170
Sodium hypochlorite required, gallons/year	4,170
Required 7 day storage volume (corrected for decay of chlorine), gallons	4,300
Sodium bisulfite dosage, mg/L	1.0
Delivered sodium bisulfite solution strength, lb/gal	3.5
Sodium bisulfite use at peak week flow, lb/day	4,170
Required storage volume (7 days at peak week flow), gallons	1,191

TABLE 12
Option 4: UV Disinfection System for the Disinfection of MBR Effluent for the Brightwater Plant

Parameter	Low pressure UV	Medium pressure UV
Phase I average annual flow, mgd	31	31
Phase II average annual flow, mgd	47	47
Maximum flow rate, mgd	56	56
Transmittance, %	65	65
No. of channels	2	1
No. of banks per channel	3	3
No. of modules per bank	5	3
No. of lamps/module	18	20
Total no. of lamps required	540	180
Channel length, feet	35.8	37.9
Channel width, inches	60	64
Channel depth, inches	61	155
Total Power Draw, kW	162	504
Phase I estimated average power, kW	80	191

TABLE 12
Option 4: UV Disinfection System for the Disinfection of MBR Effluent for the Brightwater Plant

Parameter	Low pressure UV	Medium pressure UV
Hrs per year at avg. power	8,760	8,760
Phase I annual total kWh consumed	700,800	1,673,160
Phase I average power consumed, kWh/day	1,920	4,584

ALTERNATIVE EVALUATION AND RECOMMENDATION

The alternatives developed above are evaluated in the following sections. Two methods are used in this evaluation. The first is a cost evaluation, to determine the life-cycle cost of each alternative based on a 40-year life cycle at a 3 percent return rate. The second method uses non-monetary rankings, such as ease of operation, health and safety, etc. to rank the alternatives.

Cost Evaluation of Disinfection Options

Order-of-magnitude cost estimates were prepared for each of the four disinfection options. The cost estimate for each disinfection option reflects the proposed option, as described above. In general, equipment costs were estimated based on budgetary pricing provided by manufacturers. The cost of other items, such as concrete and buildings, were estimated based on appropriate multiplier allowance for installing the equipment. A contingency of 20 percent and sales tax of 8.9 percent are factored into the total capital costs. A 35 percent factor for engineering, legal, and administration was included for all alternatives. These factors are consistent with previous estimate markups used for the Brightwater project. The estimates were used for relative comparisons and should not be used for final budgeting of a selected alternative. Once a particular alternative is selected, further project definition and predesign work will be required to better define the scope and prepare a more complete cost estimate. The capital cost comparisons are provided in Table 13. The estimated construction costs for the sodium hypochlorite and sodium bisulfite feed facilities are shown in Table 14. The annual O&M costs are presented in Table 15 and include labor, electricity, chemicals, and other alternative-specific costs.

TABLE 13
Phase I Capital Cost Comparison of Disinfection Options for the Brightwater Plant, 2003 Dollars

Item	Option 1 Sodium hypochlorite delivered	Option 2A Low pressure high Intensity UV-separate	Option 2B Medium pressure high intensity UV-separate	Option 3A Low pressure high intensity UV-combined	Option 3B Medium pressure high intensity UV-combined	Option 4 Medium pressure high intensity UV disinfection and hypochlorite
Equipment cost	$950,000	$2,290,000	$2,266,000	$2,100,000	$1,961,000	$1,614,000
Installation	$665,000	$1,603,000	$1,586,000	$1,470,000	$1,374,000	$1,130,000
Construction cost, subtotal	$1,615,000	$3,893,000	$3,852,200	$3,570,000	$3,335,000	$2,740,000

TABLE 13
Phase I Capital Cost Comparison of Disinfection Options for the Brightwater Plant, 2003 Dollars

Item	Option 1 Sodium hypochlorite delivered	Option 2A Low pressure high Intensity UV-separate	Option 2B Medium pressure high intensity UV-separate	Option 3A Low pressure high intensity UV-combined	Option 3B Medium pressure high intensity UV-combined	Option 4 Medium pressure high intensity UV disinfection and hypochlorite
Contingency (20%)	$323,000	$779,000	$770,000	$714,000	$667,000	$549,000
Subtotal	$1,938,000	$4,672,000	$4,622,000	$4,284,000	$4,002,000	$3,289,000
Sales tax (8.9%)	$172,000	$416,000	$411,000	$381,000	$356,000	$293,000
Subtotal	$2,110,000	$5,088,000	$5,033,000	$4,665,000	$4,358,000	$3,582,000
Engineering, legal & admin. (35%)	$739,000	$1,781,000	$1,762,000	$1,633,000	$1,525,000	$1,254,000
Total Project Capital Cost	$2,849,000	$6,869,000	$6,795,000	$6,298,000	$5,883,000	$4,836,000

TABLE 14
Breakdown of Estimated Phase I Construction Costs of the Chemical Feed Facilities for the Brightwater Plant, 2003 Dollars

Item	Sodium hypochlorite	Sodium bisulfite	Both facilities
Location	Treatment Plant	Portal 41	
Sitework	$15,000	$10,000	$25,000
Chemical Feed Bldg.	$100,000	$75,000	$175,000
Containment Area	$150,000	$60,000	$210,000
Storage Tanks	$80,000	$40,000	$120,000
Pumps & Valves	$22,000	$11,000	$33,000
Site Utilities	$10,000	$7,000	$17,000
Unloading Station	$20,000	$15,000	$35,000
Process Piping	$90,000	$50,000	$140,000
Electrical	$73,000	$43,000	$116,000
I&C	$50,000	$29,000	$79,000
Equipment/Materials	$610,000	$340,000	$950,000
Labor, O&P	$427,000	$238,000	$665,000
Total Construction	**$1,037,000**	**$578,000**	**$1,615,000**

TABLE 15
Phase I Annual O&M Cost Comparison of Disinfection Options for the Brightwater Plant, 2003 Dollars

Item	Option 1 Sodium hypochlor-ite delivered	Option 2a Low pressure high intensity UV-separate	Option 2b Medium pressure high intensity UV-separate	Option 3a Low pressure high intensity UV - combined	Option 3b medium pressure high intensity UV-combined	Option 4 Medium pressure high intensity UV disinfection and hypochlorite
Chemicals/Materials						
Sodium hypochlorite ($0.55/gal)	$116,000	$0	$0	$0	$0	$2,400
Bisulfite ($0.755/gal)	$20,100	$0	$0	$0	$0	$900
UV lamp replacement	$0	$78,000	$42,500	$83,000	$29,000	$21,000
UV ballast replacement	$0	$7,000	$7,000	$7,000	$7,000	$4,000
Spare parts allowance	$10,000	$15,000	$15,000	$20,000	$20,000	$10,000
Labor ($43/hour)						
Operations	$34,000	$10,000	$10,000	$17,000	$17,000	$10,000
Maintenance	$34,000	$10,000	$10,000	$17,000	$17,000	$10,000
Power ($0.05/kW-hr)						
Electric usage	$1,600	$36,000	$87,000	$48,000	$120,000	$84,000
Total Annual Costs	**$217,000**	**$156,000**	**$171,000**	**$192,000**	**$210,000**	**$142,000**

The results indicate that the sodium hypochlorite delivered option has the lowest capital costs. The UV and hypochlorite combination option has the second lowest capital cost. The combined flow disinfection using medium pressure high intensity UV option has the lower capital cost of the UV options. The split stream disinfection using low pressure high intensity UV has the highest capital cost but the lowest annual costs. Second lowest is the UV disinfection and hypochlorite combination option.

Present value costs are shown in Table 16. The present value cost is based on an interest rate of three percent over 20 years, resulting in a present value factor of 14.88.

TABLE 16
Phase I Present Value Cost Comparison of Disinfection Options for the Brightwater Plant, 2003 Dollars[1]

Item	Option 1 Sodium hypochlorite delivered	Option 2A Low pressure high intensity UV- separate	Option 2B Medium pressure high intensity UV-separate	Option 3A Low pressure high intensity UV-combined	Option 3B Medium pressure high intensity UV-combined	Option 4 Medium pressure high intensity UV disinfection and hypochlorite
Capital costs	$2,849,000	$6,869,000	$6,795,000	$6,298,000	$5,883,000	$4,836,000
Annual costs	$217,000	$156,000	$171,000	$192,000	$210,000	$142,000
Present value of annual costs	$3,229,000	$2,321,000	$2,544,000	$2,857,000	$3,125,000	$2,113,000
Total present value	**$6,078,000**	**$9,190,000**	**$9,339,000**	**$9,155,000**	**$9,008,000**	**$6,949,000**

[1] Present value analysis period of 20 years at 3 percent, resulting series present value factor = 14.88.

Combining capital and annual costs, the present value cost comparison shows that hypochlorite disinfection is the least costly disinfection approach.

Non-Monetary Considerations

A number of non-monetary considerations were identified for the options and a qualitative evaluation was performed. A summary of the non-monetary evaluation is presented in Table 17. Each option is ranked as Good, Neutral, or Poor with respect to each of the considerations. A numerical score is assigned to the options for each criterion in Table 17.

TABLE 17
Relative Comparison of Non-Monetary Features of the Disinfection Options

Category/Features	Delivered sodium hypochlorite	Low pressure high intensity UV	Medium pressure high intensity UV
Handling Safety	0	+	+
Off-site/Public Safety	0	+	+
Chemical Supply Reliability	0	+	+
Equipment Reliability	+	0	0
Ability to Handle Process Upsets	+	0	0
Potential Adverse Impact to Receiving Water Quality	0	+	+
Ease of Operation	0	0	0
Ease of Maintenance	0	-	-
Space Requirements	+	+	+
Chemical Handling Requirements	-	+	+

TABLE 17
Relative Comparison of Non-Monetary Features of the Disinfection Options

Category/Features	Delivered sodium hypochlorite	Low pressure high intensity UV	Medium pressure high intensity UV
Process Flexibility	+	+	+
Ease of Expansion	+	-	-
TOTAL SCORE	+4	+5	+5

Key: (+) = Good, (0) = Neutral, (-) = Poor

Handling Safety

Sodium hypochlorite is classified as a corrosive and irritating chemical. There is risk of exposure to chemicals during unloading and routine operation and maintenance activities. There is always a risk that an acidic chemical will be inadvertently mixed with the hypochlorite, resulting in chlorine gas fuming.

Delivered sodium hypochlorite option is ranked neutral for plant staff safety because the 10 to 15 percent solution poses the relatively greater risk to operators. The UV options are ranked good for plant staff safety because they do not involve the handling of any chemical, assuming that proper procedures are followed in operating and maintaining the UV systems.

Offsite/Public Safety

Specific concerns include a chemical release at the site that then migrates offsite.

The hypochlorite option is ranked neutral because facilities would be designed with secondary containment and there is minimal risk of exposure to the public. The UV options are ranked as good because no chemical release can occur.

Chemical Supply Reliability

At issue is the dependence on deliveries of chemicals from offsite and/or assurance that future offsite chemical supplies would be stable and reliable.

The delivered hypochlorite option is ranked as neutral because experience has shown that truck supplies and deliveries are generally reliable. However, the UV options do not require any chemical delivery so they are ranked good.

An analysis of rail delivery for both the South Plant and Brightwater showed that rail delivery, while possible, is not reliable. Rail cars can be delayed for days. For this reason, rail delivery has not been considered further for Brightwater.

Equipment Reliability

All three options have proven to be effective technologies for municipal wastewater disinfection. The delivered hypochlorite option is ranked as good because it requires the least equipment in comparison to the other two. The UV options require more equipment, such as the lamp automatic cleaning system. Therefore, they are ranked as neutral.

Ability to Handle Process Upsets

At issue is the ability of each disinfection system to consistently meet effluent requirements when there are process upsets in the plant such as high effluent solids and turbidity. Under normal operating conditions, all three options are known to be effective disinfectants. However, they vary with respect to the ability to handle process upsets. During process upset conditions, UV transmittance decreases significantly resulting in a much lower effective delivered dosage from the UV equipment. Because of the high cost of UV disinfection equipment, facilities are sized to meet effluent requirements under design conditions that do not reflect conditions during process upsets. It would be cost prohibitive to provide UV equipment sized to meet effluent requirements during process upset conditions.

The effectiveness of chlorine-based systems, which is not related to UV transmittance, is not adversely affected by upset process conditions. In addition, while still limited by the capacity of the chemical delivery system, chlorine-based systems can be sized to deliver the elevated dosages required to meet disinfection requirements during a process upset without significant capital cost impacts. For these reasons, the sodium hypochlorite option is ranked as good, and the UV options are ranked as neutral.

Adverse Impact to Receiving Water Quality

At issue is the ability of each option to minimize introduction of disinfection byproducts to receiving waters. For example, chlorine-based disinfectants use oxidation as the means to kill pathogens and have been shown to produce very low levels of harmful compounds (i.e., halogenated organic compounds such as haloacetic acids (HAAs) and trihalomethanes (THMs). UV disinfection, however, does not materially alter effluent water quality. The potential of mercury contamination of the wastewater effluent is minimal due to the small amount of mercury (1 mg) per lamp and the unlikely occurrence of lamp breakage and mercury leakage. The fact that UV disinfection technology has been used widely in drinking water treatment indicates confidence about the limited impact of UV disinfection on water quality.

The UV options are ranked as good because they eliminate the use of chlorine-based disinfectants producing HAAs and THMs. Although the hypochlorite option results in higher production of HAAs and THMs, these compounds are currently not regulated by the EPA, nor have they been proven to have an adverse impact on receiving water quality in marine outfall environments. Nevertheless, the hypochlorite option is ranked as neutral with respect to adverse impacts to receiving water quality due to current uncertainties about the actual adverse effects to water quality. We are currently beginning to see strict limitations on THMs in treatment plant effluents at other facilities on the west coast.

Ease of Operation

Both the delivered hypochlorite and UV option systems are considered relatively easy to operate. Therefore, they are all ranked as neutral.

Ease of Maintenance

Compared with chemical-based disinfection systems, UV system equipment and components generally require more maintenance. Also, increased algae and slime growth in the outfall is possible with UV disinfection because of the absence of a residual disinfectant in the effluent.

Period dosing of hypochlorite may be required to maintain the hydraulic capacity of the outfall. Therefore, the UV options are ranked as poor for ease of maintenance. The delivered hypochlorite options are ranked as neutral with respect to this evaluation criterion.

Space Requirements

Options are ranked as comparable, provided that the ETS is used for contact, because they would have smallest footprint requirement for the disinfection system. Although the delivered hypochlorite option does not need space for generation, the tank trucks for longer time storage would occupy considerable space. Therefore, the hypochlorite option is ranked as neutral.

Chemical Handling Requirements

At issue is the frequency and complexity of chemicals handled at the plant, increasing the risk of accidental spills.

Similar to plant staff safety concerns, the delivered hypochlorite option involves handling of significant quantities of chemical in more concentrated solution, so it is ranked as poor. The UV options do not require chemical handling, thus are ranked as good with respect to this evaluation criterion.

Process Flexibility

At issue is the ability of each option to accommodate changes in plant flows and dosing requirements. All of the technologies can handle changes in flow easily and quickly, with changes in chemical dose or changes in light output. All of these technologies can also handle changes in effluent quality equally well. Thus, all options receive a rating of good.

Ease of Construction

At issue is the ability of each option to accommodate capacity expansions through the addition of additional units, tankage, etc. The hypochlorite alternative received a good rating because expansion for this option involves the addition of pumps and piping only, with possibly the need to add additional tanks. The UV options receive a poor rating because expansion of these options involved the construction of new channels and the installation of additional UV units at substantial capital cost.

CONCLUSIONS

The following conclusions are reached from this investigation:

1. Sodium hypochlorite is the least costly disinfection technology for both the MBR and blended wet weather flow streams.

2. UV disinfection would be effective for disinfection of the MBR effluent.

3. UV disinfection is not economically attractive for disinfection of the ballasted sedimentation system effluent due to the large capital investment required compared to the low actual utilization rate.

4. Low pressure, high intensity UV disinfection is the most cost-effective technology if UV is the selected process for MBR effluent treatment. UV disinfection, while not the least

cost option, would be attractive if future NPDES permits contain limits on THMs or very low residual chlorine limits.

5. Chlorine contact for disinfection can be successfully provided in the ETS.

6. A complete mix system is required at the point of hypochlorite addition to achieve effective disinfection at the lowest overall cost.

7. Dechlorination of the effluent may be required and the location of a dechlorination facility would depend on the permit conditions that would likely be imposed to demonstrate adequate disinfection. Portal 5 is the recommended location based on current understanding of project requirements.

8. Dechlorination may only be required during periods of high flow or bypassing, because natural decay of the chlorine residual may be sufficient in the ETS upstream of the discharge to Puget Sound.

9. UV disinfection would be used for the production of reclaimed water for off-site reuse.

RECOMMENDED ALTERNATIVE

The following alternative is recommended for implementation for the Brightwater facility:

1. The recommended alternative for disinfection of both the MBR effluent and the ballasted sedimentation (bypassed flow) effluent is sodium hypochlorite. This approach offers the lowest 20-year present value, and is consistent with disinfection practices at other King County treatment facilities.

2. The estimated total project cost of the recommended option is $2,849,000. The estimated annual O&M cost of this option is $217,000. The 20-year present value cost is $6,078,000.

3. The analysis is based on an assumed sodium hypochlorite dose rate of 2 mg/L for the MBR effluent and 10 mg/L for the ballasted sedimentation effluent. These dose rates are conservative. Actual dose rates should be determined experimentally.

4. A dedicated sodium hypochlorite storage and feed system would be installed at the proposed Route 9 treatment plant site alternative. The facility would include three 5,000-gallon storage tanks (Phase I) located within a concrete spill containment structure, a pump/electrical building, unloading area with spill containment, and all related piping and instrumentation. One additional tank would be required for Phase II of the Plant.

5. A dedicated sodium bisulfite feed facility would be constructed in the vicinity of proposed Portal 5. The facility would include one service tank and one redundant storage tank within a concrete spill containment sump, a pump/electrical building and related piping and instrumentation systems.

6. Chlorine contact would be provided in the ETS upstream of proposed Portal 5. Adequate contact time is available in the section of the ETS upstream of proposed Portal 41, and additional contact time is provided between proposed Portal 41 and proposed Portal 5.

7. Chlorine residual should be monitored at proposed Portal 5 and sodium bisulfite added when required to meet permit conditions. ORP control of the dechlorination process is recommended.

8. Dechlorination would only be required under certain conditions of flow and residual chlorine concentration. Otherwise, natural decay in the residual in the ETS would be sufficient to meet permit.

9. Annual treatment of the ETS may be required to minimize regrowth and slime layer formation. Sodium hypochlorite would be used for slime control and dechlorination with sodium bisulfite at the outfall would be required.

10. Provision of low pressure, high intensity UV for disinfection of MBR effluent should be considered if permit limits on THMs are established. Space should be set aside for this possibility.

REFERENCES

CH2M HILL, *Draft Evaluation of Disinfection Processes for the Brightwater Siting Project*, May 15, 2002.

Jitnuyanont, P. and Bucher, B., *UV Transmittance Study of King County Wastewater*, January 2003.

National Water Research Institute (NWRI), *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*, December 2000.

Washington State Department of Ecology, *Water Reclamation and Reuse Standards,* September 1997.

ATTACHMENT A - UV Transmittance Study of King County Wastewater

UV Transmittance Study of King County Wastewater

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King County Wastewater Treatment Division
Technology Assessment Program
January 2003

Background

Ultraviolet (UV) radiation is a disinfection process where UV in the wavelengths between 240 to 280 nm is applied to the water and cause inactivation of microorganism cells. The process is proven to be effective with several advantages over chlorination such as resiliency to change in pH and temperature.

The efficiency of UV disinfection depends on the dose and water quality. The dose is directly proportional to intensity and exposure time. The presence of dissolved or suspended matter in the water can hinder the effectiveness of the treatment, since they can absorb the energy and shield the microorganisms from the radiation. Also, some constituents such as iron, sulfides, nitrites and phenols can absorb UV light. The UV dosage demand is indicated by the percent transmittance, which is unique for a specific water and must be determined experimentally for each application.

UV disinfection is one of the technologies being considered for the Sammamish Water Reclamation plant. The project is now in the technology selection/design phase. In order to aid the decision-making and design process, a study was conduct to assess the UV treatability for the Sammamish reuse project. Samples were taken from the Sammamish raw sewage; influent and effluent from West Point Plant (WP), South Plant (SP) and Membrane Bioreactor (MBR) pilot plant. South Plant secondary process is conventional activated sludge, while WP uses a high purity oxygen system.

The goals of this study are: 1) to collect UV transmittance data for the Sammamish raw water, 2) to compare the UV transmittance of the effluent from conventional treatment and MBR, 3) to assess the viability of using UV disinfection for Sammamish Reclamation Plant.

Methodology

From September 23 – 26, 2002, samples were collected from Sammamish raw sewage; influent and effluent of West Point Plant, South Plant and MBR pilot plant. All samples were composite samples, except for MBR samples, which were grab samples. All samples were filtered through filters with 0.45 µm pore size. For the effluent samples, both filtered and unfiltered samples were analyzed. For the influent samples, only filtered samples were analyzed.

Samples were measured for absorbance at 254 nm. UV transmittance was calculated from the absorbance using the equation:

$T = 100 \times 10^{(-A)}$

When: A = transmittance (1/cm)

T = % transmittance

Result and Discussion

The data from the four sources were presented in the table below.

Location	Date	UV transmittance		
		Influent	Effluent	Unfiltered Effluent
MBR pilot	9/24/2002	45.4%	67.3%	65.0%
	9/25/2002	42.7%	65.8%	65.0%
	9/26/2002	44.3%	66.7%	64.1%
South Plant	9/24/2002	37.6%	59.2%	46.7%
	9/25/2002	38.5%	55.0%	45.3%
	9/26/2002	38.4%	58.5%	48.5%
Sammamish	9/24/2002	37.8%		
	9/25/2002	36.9%		
	9/26/2002	40.1%		
West Point	9/24/2002	46.9%	69.2%	59.8%
	9/25/2002	46.9%	67.0%	57.8%
	9/26/2002	45.4%	65.9%	56.6%

Comparing conventional treatment with MBR.

The influent of West Point Plant and MBR pilot plant comes from the same source, but samples were taken at different locations. The UV transmittance of both influents is very similar (42-45% and 45-47%). However, the unfiltered effluent from West Point has substantially lower UV transmittance than that of MBR pilot plant, but the filtered effluent from both processes are comparable. This indicated that the MBR process, which is a physical barrier, can remove more filterable constituents than the conventional process. Therefore, effluent from the MBR is more suitable for UV disinfection.

Comparing filtered and unfiltered effluent

The MBR effluent shows little improvement of the UV transmittance in the filtered sample, compared to unfiltered ones. However, for the WP and SP samples, the improvements were more substantial (10%). The transmittance of WP filtered effluent is very close to the MBR effluent, both filtered and unfiltered. Therefore, it may be speculated that if the MBR is used for treating SP influent, the effluent will be comparable to that of filtered SP effluent.

Comparing raw water quality

The WP and SP both use conventional treatment. The influent of WP has higher UV transmittance. Both filtered and unfiltered effluent from WP has higher UV transmittance, also. This can indicated that the ability of a conventional process to improve UV transmittance depends on the UV transmittance of the raw water.

Generally, the UV disinfection is best suit the effluent stream with unfiltered effluent transmittance at 254 nm of higher than 65-70%. With lower transmittance, it is not impossible, but will require more UV source and contact time. The unfiltered effluent from MBR pilot is around 65%, which is on the borderline. The unfiltered effluents from South Plant and West Point have lower transmittance, 45-48% for South Plant and 56-59% for West Point.

Since the Sammamish raw water is similar to SP influent it is possible that if MBR process is used, the transmittance of the effluent will be comparable to the SP filtered effluent (55-60%). A UV dose respond (Collimated Beam) study of SP effluent (Appendix A) shows that at the dose of 60 mWs/cm^2 the fecal coliform was 246/100mL, which is higher than the requirement of 200/mL.

However, there are many other parameters that affect UV transmittance. Therefore, once can not accurately predict that the same level of treatment seen with SP influent will be achieved if the same treatment is applied to Sammamish raw water.

Conclusion

1. MBR produce a better quality effluent than conventional process in term of UV transmittance.
2. The unfiltered effluent from MBR is about 65%, which is on a borderline for the UV process to be viable.
3. Sammamish raw water has low UV transmittance, which can result in low UV transmittance of the effluent.

References

1. Water Environment Research Foundation (1995). *Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance.*
2. Environmental Protection Agency (1999). *EPA Guidance Manual: Alternative Disinfectants and Oxidants.*

Appendix A: Water Analysis Report from South Plant

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Trojan

WATER ANALYSIS REPORT

To: Dean Boode

Project Name:**King County South - Renton, WA**

Rep: Wm. Reilly Co.

Sample #: S02-1149, S02-1150

Parameters Analyzed: UV Transmittance-whole sample, UV Transmittance - filtered, TSS, UV Dose Response (Collimated Beam)

Sample Source: Secondary effluent
Process: Oxidation Ditch
Date sample taken: September 24, 2002
Date sample analysed: September 25, 2002
Disinfection Limits: 200/400 FC/100mL

Sample Treatment: No Additives

SAMPLE NO.	SAMPLE DESCRIPTION	%T	%T FILTERED	TSS (PPM)	MEAN PARTICLE SIZE (MICRONS)	%PARTICLES >31MICRONS
S02-1149	Secondary effluent - Collimated Beam September 24, 2002	51	55	18	53	52.7
S02-1150	Secondary effluent - PSA September 24, 2002	-	-	-	51.2	57.2

Collimated Beam Results

Dose (mWs/cm2)	Fecal coliform/100mL
0	248000
10	6456
20	2585
30	683
60	246

Comments:

Certified by J. Faber
Team Leader, Analytical Serv